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Lessons learned from the flood 2002 in Saxony/Germany

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Abstract: In August 2002 a heavy rainfall event lasting more than two days occurred in Saxony/Germany. This led to extreme flash floods and extreme high water levels in some left tributaries of the river Elbe in the Ore mountains (Erzgebirge). Much damage occurred: houses and bridges were destroyed, much sediment moved and a dam broke. About 20 people died.
Immediately after the event a mapping exercise of all damages arising from the flood was compiled. The hydrologic and hydraulic processes during the flood were analysed. This analysis included the genesis of the flood, the flood routing, the erosion, plain bed load transport and the sedimentation.
The analysis of such an extraordinary event can help us learn how to prevent flood damages in the future.

Description of the considered rivers and catchment areas
Several countries and many regions were affected by the big flood of the year 2002 such as Austria, the Czech Republic and Germany. The Ore mountains area (Erzgebirge) in Saxony/Germany was one of the worst hit region. These highlands are situated in the eastern part of Germany at the border between Saxony and the Czech Republic (figure 1).
Looking at historical flood records one can find many large floods associated with this region such as in 1573, 1897, 1927 and 1958. But the 2002 flood event was the highest flood even measured in this region. Both intensity and duration of precipitation of the 2002 event had not been recorded before.

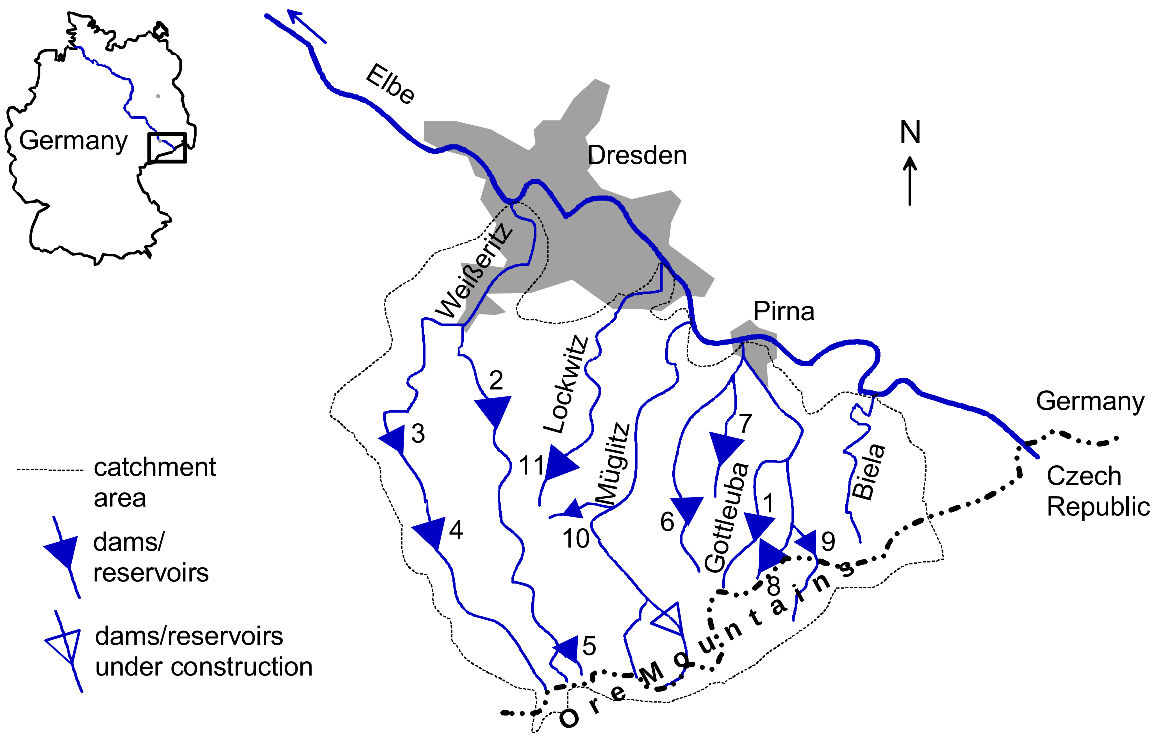

Figure 1: Area of consideration (the number of the dams refer to table 2).

The focus of this paper lies on five left tributaries of the river Elbe having its source near the peaks of the ore mountains. These tributaries are Biela, Gottleuba, Müglitz, Lockwitz and Weißeritz beginning with the most eastern (figure 1).
Sandstone dominates the geological underground in the Biela catchment area. This stone is characterized by good seepage behaviour. Granite and gneiss of the ore mountain region are found in

the other catchment areas. These stones prevent seepage and their high hardness resulted in only small decomposition and subsequent only small soil layers could develop above the rock. The rivers flow typically through narrow and deep valleys with steep scarps. With only small areas of natural flood plain lying in these valleys, water flow through the valley is intense, yielding sharp peak flows.

A few towns along the rivers are situated in natural widenings of the valleys. For more than 450 years mills have been built along the rivers to utilize the water power. Industrialisation let population increase at the beginning of the 20th century. Factories and roads were built in the valleys and new houses were constructed very close to the river banks. In the Müglitz and the Weißeritz valleys there are also rail roads. Therefore many road and railway bridges cross the rivers. These bridges typically offer only a very small discharge cross section and can hinder high level flow, resulting in big affluxes and overtopping.

The catchment area of the Biela river is dominated by forest. Agriculture and forestry characterise the catchments of the other four rivers, in equal shares. Some river sections have kept their natural behaviour. The rivers meander in the valley ground and there are trees up to the river banks. This is important to know, because many trees were washed away by the floods and blocked bridge cross sections.
All the rivers mentioned above were affected by large floods in the 19th and 20th century. Hence, the presence of embankments where towns or industry are situated, which are characterized by a regular shape of cross section. The problem of trees, wood, sediment and rubbish transported by the water during big flood events and additional damages by erosion and sedimentation of debris were also known from the records about historical flood events in this region. However no infrastructure existed to keep fallen trees, debris and the like from entering populated areas.

The Event
The rainfall from 11th–13th August 2002 exceeded historical records. In table 1 the area precipitations of the five Elbe tributaries are listed. The typical mean rainfall value is about 660 mm per year in Saxony. In 2002 the highest precipitation value near the source of the Müglitz and Weißeritz rivers, was recorded at 312 mm within 24 hours and 406 mm within 72 hours.
In addition high precipitation and humidity values were measured at the time before the event. The event caused severe flooding and damage in the river valleys.

Table 1: Intensity of precipitation during 24 and 72 hours (*LfUG 2004*).

river	**catchment area [km²]**	**areal precipitation at 08/12/2002 [mm]**	**areal precipitation from 08/11/2002 to 08/13/2002 [mm]**
Biela	104	150	191
Gottleuba	252	182	231
Müglitz	214	237	296
Lockwitz	84	194	245
Weißeritz	384	220	265

At its peak the water filled the whole bottom of the valleys. The flood reached its peak along most of the rivers sections in the night between the 12th and 13th of August. The peak discharge was held over a long time period.
Further analysis showed that the direct runoff coefficient was between 50 and 70 %. Such a high rate was caused by heavy intensity of the rainfall event, the initial soil moisture level and the low permeability of the underground material of the most catchment areas.

Analysis of damages
Damages were caused by inundation, erosion of the river banks and building foundations, blocking debris at bridges (figure 3) and weirs. Floating trees and debris drove into houses and bridges during the high level flood.

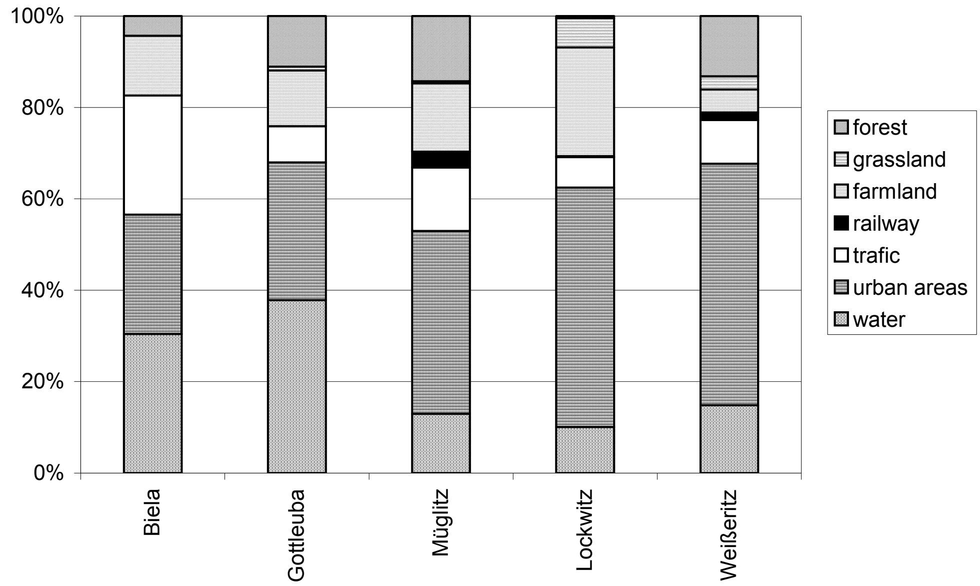

Figure 2: Percentage of the flooded area referring to land use of each considered river during the flood event 2002.

Immediately after the event a mapping exercise was compiled of the flood damage. For the most part urban areas were affected by inundation (figure 2) due to their location in the natural floodplain. In this area houses were, and, still are situated very close to the river banks and therefore the backwater effects increased water levels. Damage to property close to the river bank was clearly greater to property standing further away, as Figure 5 shows.

Figure 3: The Weißeritz river in Dresden after the flood event with a bridge blocked by trees and brushwoods.

Due to inundation of the entire valley bottom, significant debris was deposited over a large area. Embankments roads and railways were washed away (figure 4). The rapid flow eroded roads and footways, and damaged drinking water, gas, electrical mains and sewers. In addition, foundations of buildings were destroyed.

Figure 4: The Weißeritz river after the flood event with the destroyed railway line on the right bank (flow direction is from the right hand side to the left hand side).

Sediment transport, floating debris and wood

Research into the 2002 flood event provided the opportunity to analyse the effect of sediment transport in terms of the potential for causing significant damages. The transport of bed load and suspended load, the erosion of river banks and deposit of debris are natural processes belonging to river dynamics and resulting in the formation of a river bed. The point is to allow these processes in natural river sections but to protect urban areas from devastation. The Institute of Hydraulic Engineering and Applied Hydromechanics of the Dresden University of Technology gave an overview analysis of sediment transport during the 2002 flood in order to improve knowledge and get data to validate numerical theories. Another task was to review flood protection concepts special focus on sediment transport calculation and recommended sediment management for design floods.

During the 2002 flood a large amount of bed load was mobilised and transported as also reported in historical flood records. The bed load was mobilised mainly through bank erosion within meandering river sections. The river bottom was eroded especially in the steeper river reaches in the upper part of the Ore Mountains. Large amounts of bed load were transported along the main tributaries.

Figure 5: The Müglitz river after the flood event. On the left bank the abutment of a destroyed road bridge is to be seen. The corner of the house standing close to the right river bank was washed away.

Sources of bed load were embankments and walls mainly in a bad state in the mounted river sections, river banks, road embankments, railway embankments but also destroyed buildings. Cars, containers, furniture and old or shallow root trees were floating in the valleys during the flood. Deep root trees growing usually near rivers like alder trees could withstand the high level flow better.

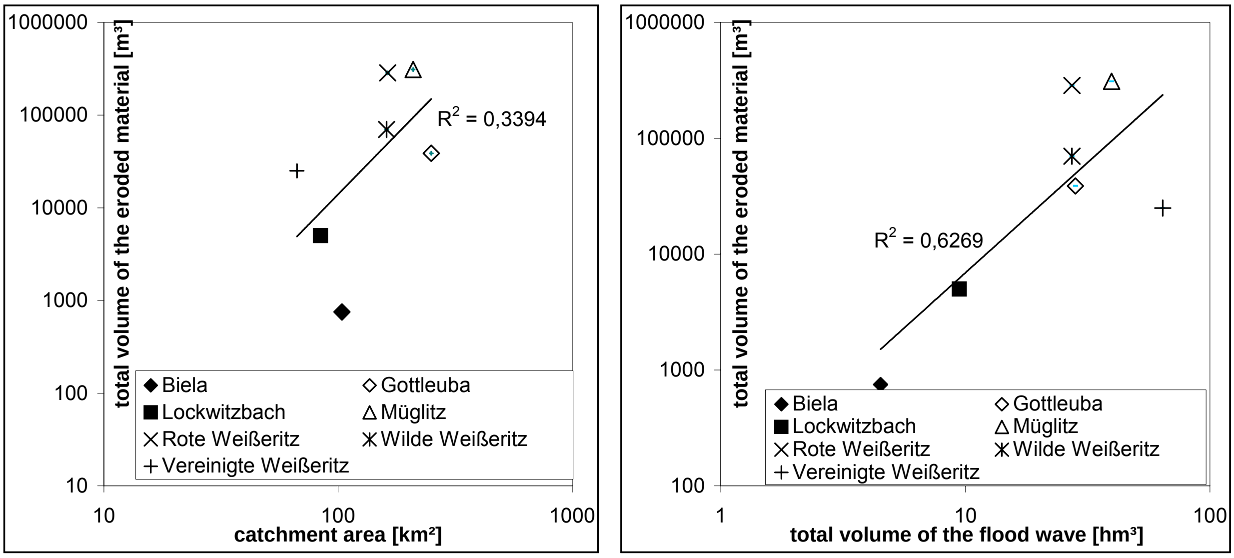

Figure 6: Total volume of the eroded material estimated for each river after the flood event 2002 versus catchment area and total volume of the flood wave.

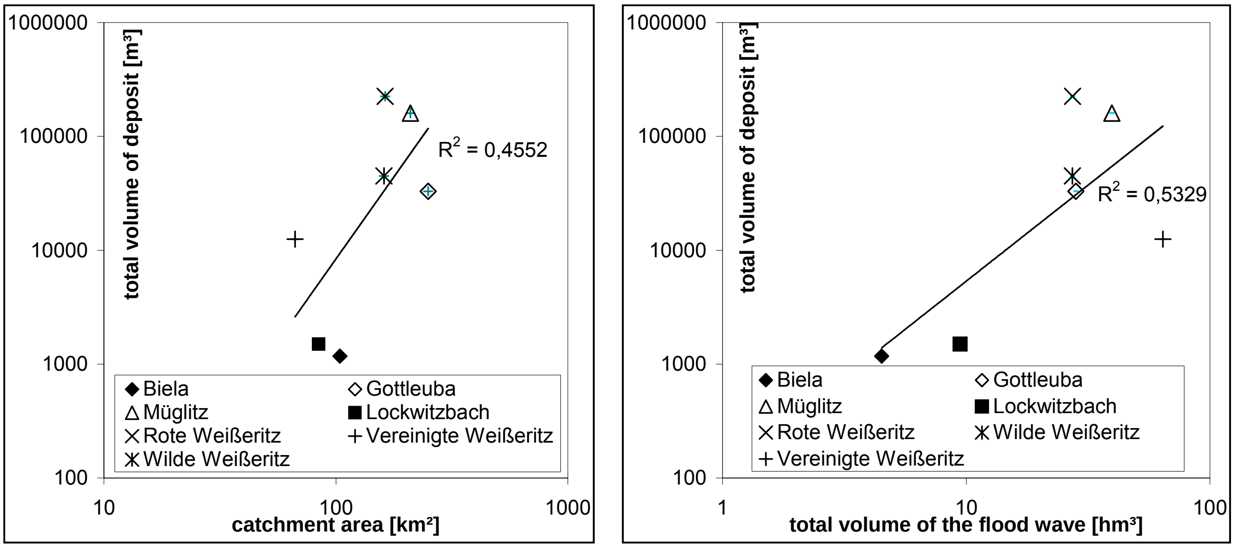

Figure 7: Total volume of the deposited material estimated for each river after the flood event 2002 versus catchment area and total volume of the flood wave.

Several weeks after the event, the volume of bed load was estimated in situ and mapped for each river. This mapping could not always acquire the total volume because river beds were cleared from deposited material and destroyed bridges a few days after the flood. Also in figures 6 and 7, one can see that the volume of sedimentation is not equal to the volume of erosion, and that the total acquired volume of erosion and sedimentation depends on the catchment area and the volume of the flood wave, with the latter considered to be more of an influence on erosion.

The amount of floating debris and transported trees also depends on the volume of the flood wave, but quantitative statements are not possible because these amounts were established only at certain points in the river valleys.

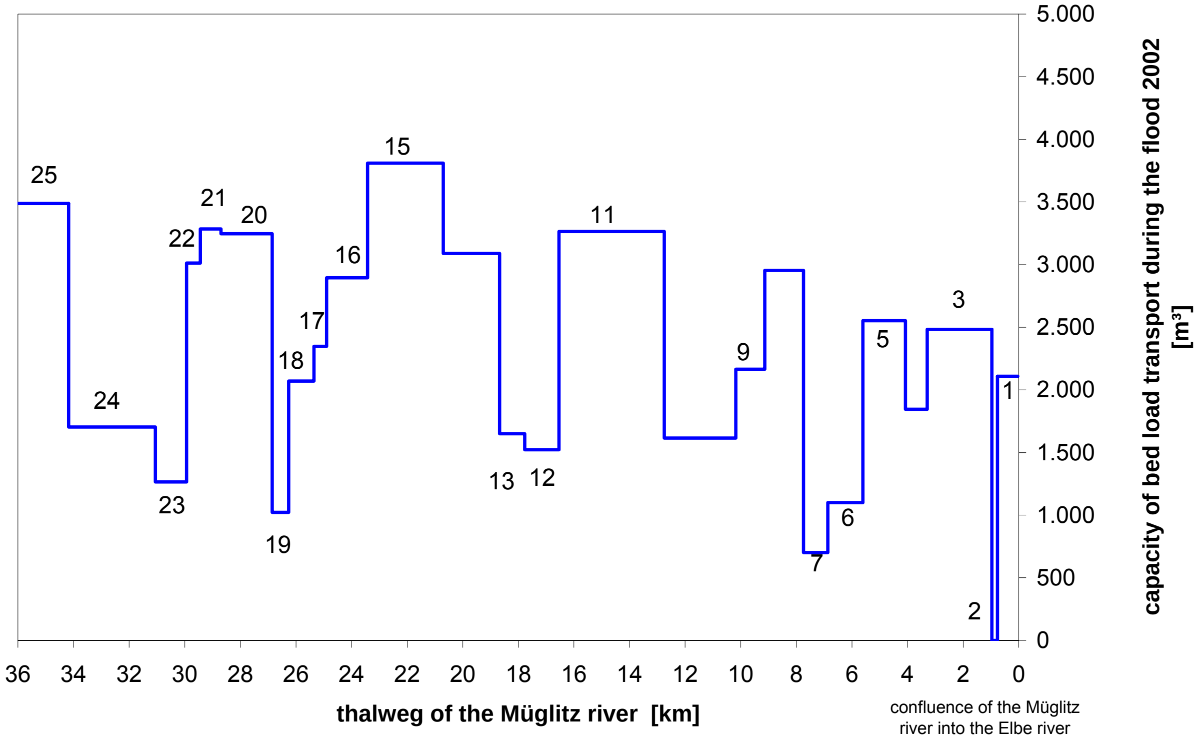

Figure 8: Calculation of theoretical capacity of bed load transport of the Müglitz river due to the flood wave in 2002.

The analysis of sediment transport has shown that the bed load was not transported over long distances. This was due to aggradation of bed load and debris, caused by obstacles such as bridges or weirs and by shallow cross sections and river reaches with a mild longitudinal slopes.

To analyse the bed load transport during the flood event, the granulometric grain size distribution of the bed load of each river was calculated using the method by *Fehr (1987)*. The theoretical capacity of bed load transport was calculated in several river reaches based on appropriate bed slope and the bed shape (figure 8) characteristics. If the calculated transport capacity of a river reach is smaller than the calculated transport capacity of the next upstream reach bed load would be deposited. In this way the natural sedimentation areas of each river were determined. Such deposition often occurred in urban areas along the river. The transport capacity is the maximum value of possible bed load transport during a specific flood event and it is not the value of bed load actually transported during the flood. The total volume of the material transported during a specific flood could be smaller as calculated transport capacity e. g. due to the fact that lesser material is disposed to erosion in mounted river beds.
The qualitative conclusions obtained by comparison of calculated transport capacity of each characteristic river reach were compared with the acquired volume of eroded and deposited bed load and some good agreement could be found (*Bornschein (2003)*).

Dams and reservoirs
5 Dams and 6 flood retention basins are situated in the catchment areas of the rivers Biela, Gottleuba, Müglitz, Lockwitz and Weißeritz (figure 1).
Since 2002, one further flood retention basin in the upper catchment area of the river Müglitz has been under construction.
Most of the dams and ponds were built after flood events in 1957 and 1958, to protect the towns and villages in the valleys. In addition some dams supply drinking water.

The new German dam standard (DIN 19700) creates two design cases for dams. The flood design case 1 covers spillway design. The appropriate design flood inflow (BHQ_1) must be controlled without any damages at all. Considering large and middle-sized storage structures the design flood inflow BHQ_1 required a return period of 1000 years. The flood design case 2 covers a check of dam structure security. The appropriate design flood inflow BHQ_2 (> BHQ_1) must be routed in such a way that the load-bearing capacity of the dam structure and thus its storage capacity are preserved. Damages to components may be acceptable if they do not affect the dam stability. The design flood of case 2 required a return period of 10,000 years considering large and middle-sized storage structures.

The first calculation of the return periods of the flood event of 2002 gave very high return periods in the range of 1000 to 10,000 years considering the time series of gauge measurements up to 2001. At some of 11 reservoirs highlighted in Table 2, the flood event yielded a very low exceedance probability, leading to the discharge capacity of the reservoirs, based on previous standards being exceeded. Nevertheless it was evident that the reservoir retention allowed a considerable peak flood reduction of the rivers in many cases. The new operation rules after 2002 guarantee an extended flood storage to improve retention.

Table 2: Data of dam inflow and outflow discharge during the flood event 2002 (*Sieber 2002; SMUL 2003; Schumann & Sieber 2005*).

No.	**dam**	**design spillway capacity [m³/s]**	**maximum inflow discharge of the design flood case 2 DIN 19700 before 2002 [m³/s]**	**maximum inflow discharge at 08/13/2002 [m³/s]**	**maximum spillway discharge at 08/13/2002 [m³/s]**
1	**Gottleuba**	180	188	67,9	35
2	**Malter**	156.3	200	228.1	222
3	**Klingenberg**	86	150	170	167.7
4	**Lehnmühle**	94.2	125	155.3	114.4
5	**Altenberg**	10.9	11	12	11,1
6	**Liebstadt**	44	56	36	20.3
7	**Friedrichswalde/O.**	62	106	70.3	26,5
8	**Mordgrundbach**	80	88	25,1	4,7
9	**Buschbach**	170	158	47.2	27
10	**Glashütte**	*5*	-	26	dam break
11	**Reinhardtsgrimma**	14	31	23	17.5

Having considered the peak discharge measurements, gathered evidence from observed inflows and outflows, a return period of no better than 1 in a 1000 years was than assigned to the flood 2002 (*Schumann & Sieber (2005)*).

The damages to spillways, operational equipment and measurement instruments at all reservoirs, apart from one were in the order tolerated by DIN 19700 (*Sieber (2003)*). One small retention basin in the Müglitz catchments, the Glashütte dam, was destroyed due to the extreme discharge.

The Glashütte dam at the little river Briesnitz was built from 1951 to 1953. This river is a tributary of the river Müglitz. The cause of the decision for dam construction at this site was a heavy rainstorm event in 1948 in this catchment area. The reservoir storage was about 50,000 m³. In periods without rain the basin was empty and the Briesnitz river passed the dam through an outlet gallery (figure 9). Since the late 1990th the dam was maintained under the supervision of the Glashütte Town.

The earthfill dam with a straight dam axis had a height of 9 m. The upstream and downstream faces of the dam were covered with grass. No sealing existed in the upstream dam fill and no drainage present in the downstream dam toe.

Figure 9: Broken section of the Glashütte/Briesnitz dam from downstream in August 2002. On the right hand side (in flow direction) the ruins of the stepped spillway are visible and right in the foreground there is the downstream end of the outlet tunnel.

On the southern end of the dam a stepped spillway existed which had a capacity of about 5 m³/s just when the water level reached the dam crest. At Glashütte the Briesnitz river flows partly through a small rectangular channel and partly in an underground tunnel. This is the reason for why the discharge through the outlet tunnel was reduced to 7 m³/s, in order to protect the downstream town.

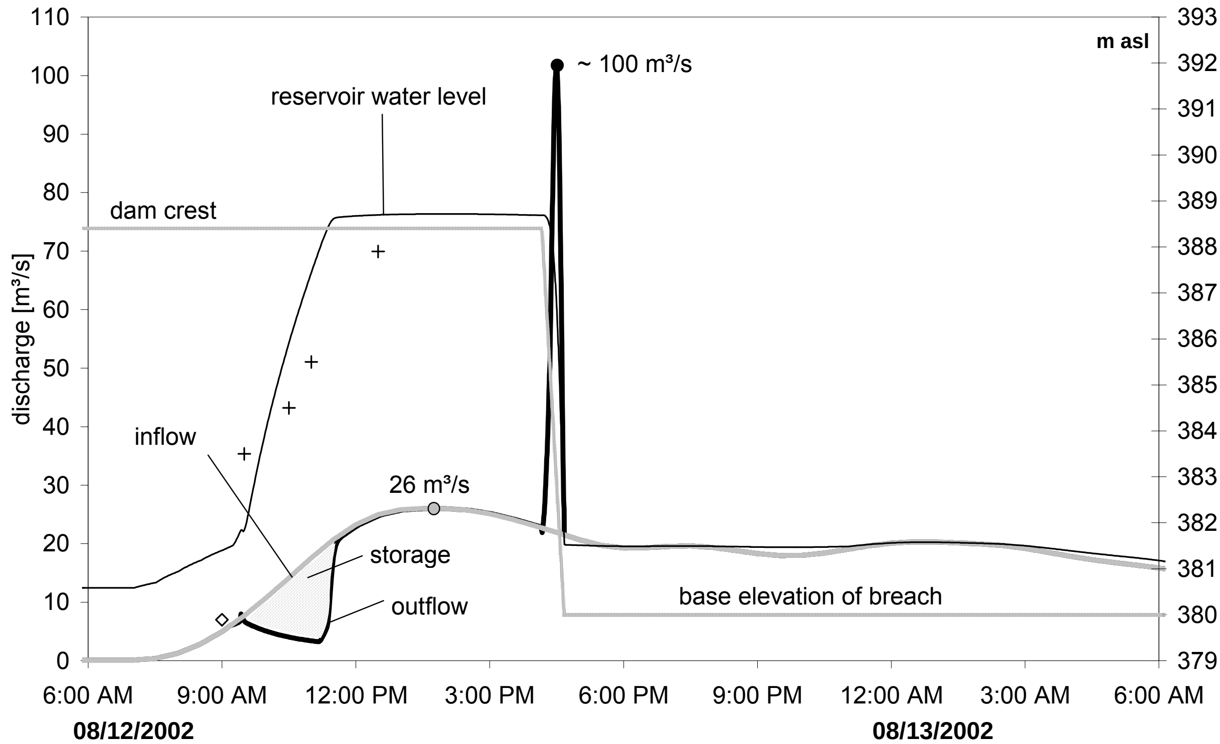

Figure 10: Calculated outflow during the flood and break event with some observed data (◊ basin began to fill; + observed basin level at several times).

The cause of the dam failure is given in very detail by *Bornschein & Pohl (2003)*. Due to the extreme rainfall event, the basin was filled and at the end the dam was overtopped. The overtopping lasted about 3 and a half hours until dam crest erosion began. Dam fill material was eroded in form of big clods, which were instantaneously transported downstream. Within half an hour the breach reached

the dam base. The volume of material removed during the dam break was calculated to be about 1700 m³.
The maximum discharge of the inflow hydrograph was about 26 m³/s due to several calculations. The maximum outflow discharge due to the dam break was about 100 m³/s (figure 10). Thus there is a discharge percentage increase of about 300 %. Figure 10 clearly shows that the storage of the basin was very small compared to the total inflowing water volume. When the dam failed the peak outflow due to the dam break did not coincide with the peak caused by the rain fall in the Müglitz river. So it could be shown that the total discharge peak in the Müglitz River was not increased by the dam break. Therefore the additional damages due to the break remained limited to the direct downstream reach of the Briesnitz basin.

Figure 11: Upstream entrance of the bottom outlet tunnel after the flood event. It was totally blocked with brush-wood and rubbish.

The relative small impact of the dam break on the Müglitz valley caused partly by the relatively small storage volume of the retention basin and partly by the extreme flood due to the rainfall event. However contributory factors of the Glashütte dam break included the insufficient dimensioning of the spillway and freebord. The situation was exasperated by the downstream outlet being congested with brush-wood, trees and rubbish (figure 11).

Flood protection concepts
After the flood the Saxon Federal State Ministry for Environment and Agriculture and the Saxon State Dam Authority who is responsible for a major part of the Saxon 1st order waters, provided considerable funds for immediate measures (clearing out the discharge sections from bed load, wood, broken bridges, slide cones, destroyed houses). In a next step the authorities initiated a large programme to analyse the flood, the damages, the sediment processes, to elaborate flood protection concepts. Many institutions, consultants and universities were involved in this work for all affected catchment areas in Saxony. Particular attention was turned on an integral consideration of the catchment area which is also postulated by the EU Water Framework Directive.
The principal item of these considerations are water profile calculations for the actual state and future plannings (1-D, steady non-uniform; unsteady, and if required 2-D or hydraulic model tests). The results of this work were summarized in inundation maps, intensity maps and hazard maps as well as in proposals for better flood protection in future.
To visualize the degree of risk, the return period and the intensity of flooding are superimposed and mapped in a hazard stage chart. This is also the basis for hazard maps. The hazard stages are determined separately for each type of hazard and marked to set out inundation, bank erosion or aggradation. If an area faced different types of hazard this would be marked by index and box number with the colour of the highest hazard stage (figure 12). The hazard maps therefore served as a

decision tool for development planning and flood protection, and will be made available to all local authorities to inform people and identify potential flood hot spots.

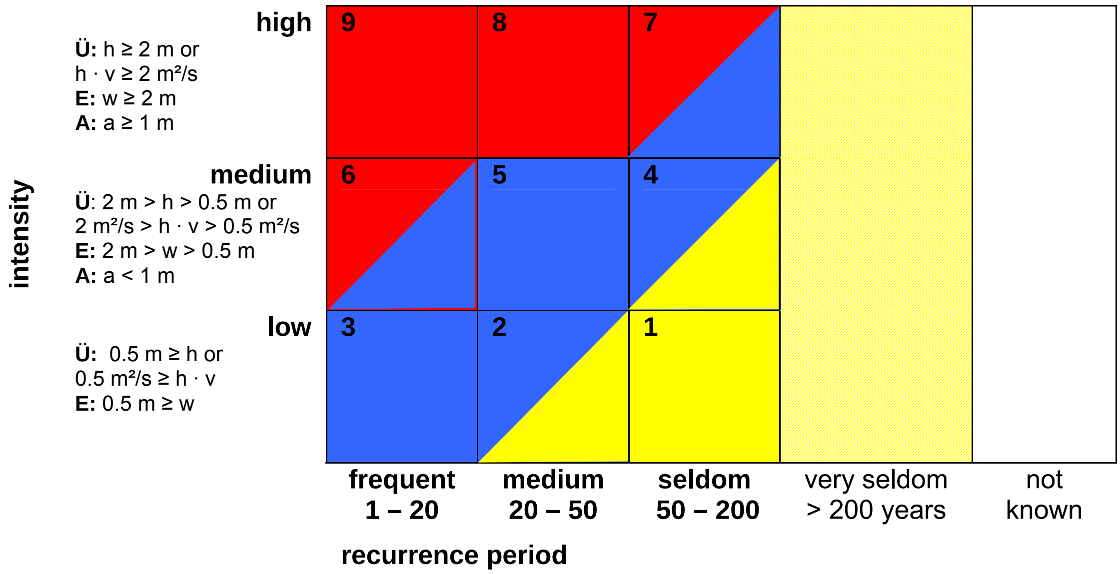

Figure 12: flood hazard stage chart (h = water depth, a = aggradation, sediment deposition depth, v = flow velocity, w = bank erosion width, Ü = inundation, E = erosion, A = aggradation, bed load deposit).

Within the frame of these concepts a more distinguished level of protection depending on the land use can be achieved, which will be readable from the hazard stage maps (*LTV 2003*). When planning better flood protection, the experts and consultants had to also evaluate many proposals from concerned people, in view of feasibility and protection effect.

Figure 13: The St.-Gotthard motorway as a flood channel of the river Reuss in Switzerland. On the right side there is a flood protection wall.

A postulation often heard is: “Give the rivers more space“. If one thinks of large gated polders with controlled flooding this would be a good possibility to reduce flow peaks. But the example in figure 14 shows that even if using a 2 km² large polder in Dresden, the Saxon capital, flooded just in the right moment, can reduce the peak stage only by a few decimetres (right). If the controlled flooding starts to early (e.g. due to inexact forecast) almost no peak reduction can be achieved. But the problem is that in the mountain region no potential polder areas are available at all, so that this proposal could not be realized.

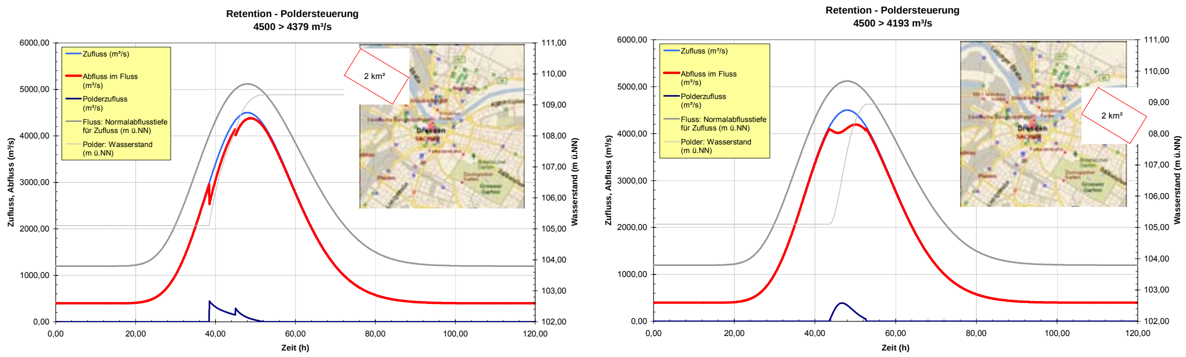

Figure 14: Example for controlled polder flooding. left: due to unexact forecast the polder was flooded to early. Example data: river bed 102,0 m a.s.l; width 250 m; fixed overflow crest 105,2; longitudinal bottom slope 0,0003; Strickler coefficient 36 $m^{1/3}/s$; water level when opening the 1st of two dike gates 108,0; water level when opening the 2nd dike gate 109,5; dike crest 110,5; crest width 1414; polder bottom 105; gate width 2 x 20 m; flood hydrograph: shape factor 20; time to peak 48 h; peak flow Q_S = 4500 m³/s; time step (dh) 0,08 h; MQ (Basis) = 400 m³/s; polder reservoir surface A_o = 2 km²).

If one considers an enlargement of all downstream discharge sections and the removal of all narrow sections and obstacles, this could work hydraulically, but may not be able to be realized in most cases, due to property, competitive use of the land or to high costs.
If one thinks of a local widening of the discharge section, e.g. by removing main dikes along a short reach this could result in a moderate *higher* water level than in the old state, which can be shown by application of Bernoulli's law.

Another proposal is to use streets as flood-bypass-channels. The authors have proposed this for a smaller stream in Dresden. There is already such a project realized: In Switzerland the St. Gotthard Motorway on the northern side of the alps can work as a bypass (figure 13). Other proposals are flood tunnels under a city or fuse plug weirs to give way when floods occur. Also bypass tunnels in the way of large sewers have been proposed for several towns in Saxony such as Pirna (on the Elbe), Glashütte (on Müglitz and Briesnitz) and Grimma (at the Mulde river).

An often asked question is "How much money are we able and willing to spend on flood protection?" From the only viewpoint of economic efficiency it could be preferable not to invest in flood protection but to compensate flood damages after the recurrence every 30 or 50 years. Fortunately the problem has not been discussed in this way particularly as personal injuries would not be considered by this reflection.

Conclusions
The big flood event occurring in Saxony/Germany in 2002 and its analysis gave a better understanding of the processes and damages accompanying such a high level flow in mountain valleys. Despite numerous flood protection works existing at that time only a limited protection to people and property could be provided against such an extraordinary flood.
From the experience a comprehensive catalogue of conclusions and proposals was compiled which include the following examples in summary form.

- Updating and re-evaluation of the design peak flows of dams, weirs and river reaches, evaluation of historical flood events
- improvement of the forecast and early warning
- flood protection concepts for all catchment areas
- Checking the stage-discharge-curves (many of them were wrong or inexact)
- Providing inundation maps, flood marks (m a.s.l) also in the streets of the cities
- Consider water propagation below ground level: groundwater, mining, sewer systems
- Improvement of individual and private flood protection
- Improvement of the set up of the public administration (q. v. *Kirchbach 2002*)
- Checking of land use, identifying hazardous zones

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